

appeared to compare favorably with those from the RMP, which were also quite variable. In 1999, sediment from the sampling station on the Napa River generated survival rates ranging from as low as 8 percent survival in August to as high as 65 percent in February. In terms of standards set by the Bay Protection and Toxic Clean-up Program, only survival rates of the Reclaimed Water Monitoring Unit fell within the 10 percent “reference envelope” standard on all testing periods (Table 5). The Program allows for user selection of a reference envelope based on standard deviation, with 10 percent being the most commonly used envelope. These standards were also met by the Undiked Marsh monitoring unit in February 2000 and January 2001, as well as the pH-adjusted Muted Tidal monitoring unit in January 2001 (Table 5).

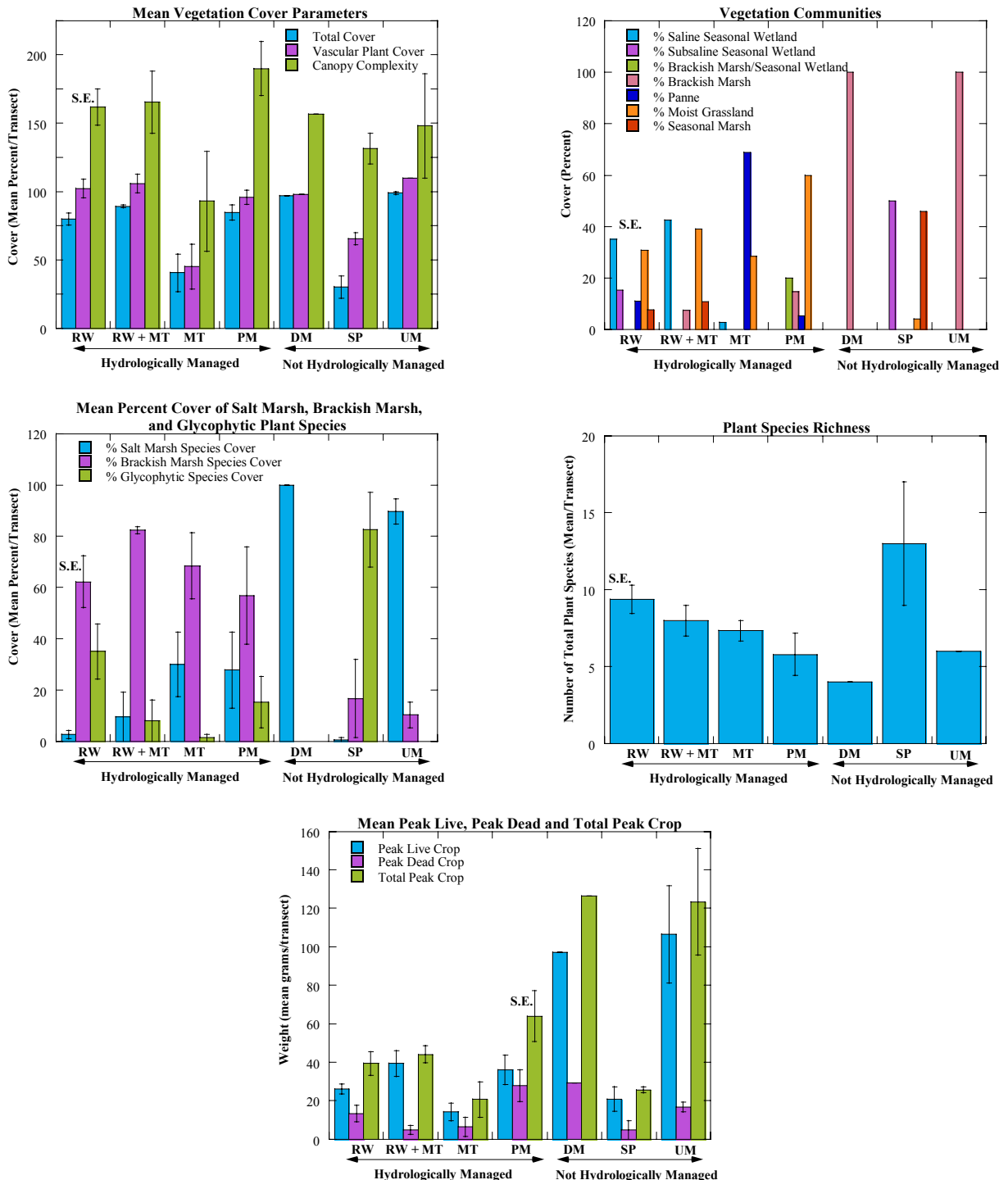
### ***Food Chain Support and Wildlife Use***

#### **Vegetation**

*Total Cover, Vascular Plant Cover, and Canopy Complexity.* A list of all plant species observed, including the ones most commonly encountered along vegetation transects, is provided in Appendix B. In general, the Reclaimed Water monitoring unit had similar total cover, vascular plant cover, and canopy complexity as other managed monitoring units. Only the unmanaged monitoring units, Diked Marsh ( $99\pm1$  percent) and Undiked Marsh ( $97\pm0$  percent), generated close to 100 percent vegetation cover. The remainder ranged from being sparsely vegetated ( $30.2\pm8.2$  percent; Seasonal Ponds) to moderately vegetated ( $89.1\pm1$  percent; Reclaimed Water + Muted Tidal), with unvegetated areas either being comprised of bare ground, including pannes, or open water areas (Figure 22). The Reclaimed Water monitoring unit averaged approximately  $80.0\pm4.4$  percent vegetation cover (Figure 22). Means for vascular plant cover, which takes into account “layering” of different plant within herb/forb and shrub strata, were generally from 1 percent (Diked Marsh) to 35 (Seasonal Pond) percent higher (Figure 22), suggesting that there was not much diversity within canopy strata.

Canopy complexity expands upon this layering to include presence of micro- and macro-algae and detritus. Among the macro-algal species or genera observed within monitoring units were *Hydrodictyon reticulatum*, *Spirogyra*, and *Ulothrix* (Table 6). Pennate diatoms (Bacillariophyceae) were the most dominant micro-algae present, typically in canopy breaks or unvegetated pannes, followed by another ochrophyte common to salt marshes, *Vaucheria* (Table 6). Unvegetated areas in the Reclaimed Water and Muted Tidal monitoring units also supported the blue-green algal genera *Oscillatoria* and *Synechocystis*, respectively (Table 6). Most of the algal taxa observed include species that occur in a variety of freshwater, brackish, and estuarine/marine habitats. As with vascular plant cover, all monitoring units displayed a jump in percent cover, but this time, the increase was more substantial. In this case, the highest canopy complexity was reported in the Passive Hydrologic Management monitoring unit ( $189.8\pm19.8$  percent), and the lowest, in the Muted Tidal monitoring unit ( $92.8\pm36.4$  percent; Figure 22).

*Vegetation Communities.* The hydrologically unmanaged monitoring units generally had a lower diversity of vegetation communities present than the managed ones. The unmanaged Diked Marsh and Undiked Marsh supported only one community (Brackish Marsh), while Seasonal Ponds supported three (subsalsine seasonal wetland, moist grassland, and seasonal marsh), with subsalsine seasonal wetland and seasonal marsh accounting for the most cover (Figure 22). Three



**Figure 22.** Vegetation parameters in Hudeman Slough Case Study monitoring units during 2000 sampling period. Data includes two transects from 1999 sampling period that were not resampled in 2000. Bars indicate standard error of the mean for sampling locations within monitoring units, when multiple sampling locations were present. (RW-reclaimed water; RW+MT-reclaimed water plus muted tidal; MT-muted tidal; PM-passive management; DM-diked marsh; SP-seasonal pond; UM-undiked marsh)

**Table 6.** Macro- and micro-algal species observed in some of the Hudeman Slough Enhancement Wetlands Case Study monitoring units.

Algae <sup>1</sup>	Monitoring Unit			
	Reclaimed Water	Reclaimed+ Muted Tidal	Muted Tidal	Passive Management
<i>Macro-Algae</i>				
<b>Chlorophyta</b>				
<i>Cladophora</i>	√			
<i>Hydrodictyon reticulatum</i>	√			
<i>Microspora</i>				√
<i>Monostroma</i>	√			
<i>Oedogonium</i>	√			
<i>Rhizoclonium</i>	√			
<i>Spirogyra</i>	√			
<i>Ulothrix</i>	√	√		
<i>Micro-Algae</i>				
<b>Chlorophyta</b>				
<i>Ankistrodesmus</i>		√		
<i>Chlamydomonas</i>		√		√
<i>Chlorococcum</i>		√		
<i>Closterium</i>	√	√	√	
<i>Tetmemorus</i>			√	
<b>Chrysophyta</b>				
<i>Tetrasporopsis</i>	√			
<b>Cyanophyta</b>				
<i>Oscillatoria</i>	√			
<i>Synechocystis</i>			√	
<b>Dinophyta</b>				
<i>Ceratium</i>	√			
<b>Ochrophyta</b>				
Bacillariophyceae				
Biraphnidineae	√	√	√	√
Raphidioidineae	√			
Tribophyceae				
<i>Tribonema</i>	√			√
<i>Vaucheria</i>	√		√	√

<sup>1</sup> Table does not represent complete inventory of algal species present.

types of vegetation communities were also observed within the managed Muted Tidal monitoring unit, with unvegetated panne being the primary one in terms of percent cover (Figure 22). The Reclaimed Water monitoring unit actually had the highest diversity of communities with five (5) present (saline seasonal wetland, subsaline seasonal wetland, panne, moist grassland, and seasonal marsh; Figure 22). Saline seasonal wetland and moist grassland accounted for the highest percent cover. The remainder of the managed monitoring units supported approximately four (4) types of communities (Figure 22).

*Plant Species Cover.* As might be expected, the highest mean percent cover of salt marsh species occurred in the Undiked Marsh (89.7±5.0 percent) and unmanaged Diked Marsh (100.0±0 percent) monitoring units, followed distantly by the Muted Tidal (30.1±12.6 percent) and Passive Hydrologic Management (27.8±14.8 percent) units (Figure 22). The lowest mean percent cover of salt marsh species was found in the Seasonal Ponds (0.7±0.7 percent), Reclaimed Water (2.7±1.5 percent), and Reclaimed Water + Muted Tidal (9.6±9.6 percent)

monitoring units (Figure 22). Brackish marsh species dominated the Reclaimed Water + Muted Tidal ( $82.4 \pm 1.45$  percent), Muted Tidal ( $68.5 \pm 12.9$  percent), Reclaimed Water ( $62.3 \pm 10.2$  percent), and Passive Hydrologic Management ( $56.9 \pm 19.0$  percent) monitoring units (Figure 22). The Reclaimed Water monitoring unit also supported a moderately high mean percent cover of glycophytic species ( $35.1 \pm 10.7$  percent), however, the only monitoring unit dominated by glycophytic species was Seasonal Ponds ( $82.6 \pm 14.6$  percent; Figure 22). A classification of species according to salinity tolerance can be found in Appendix B.

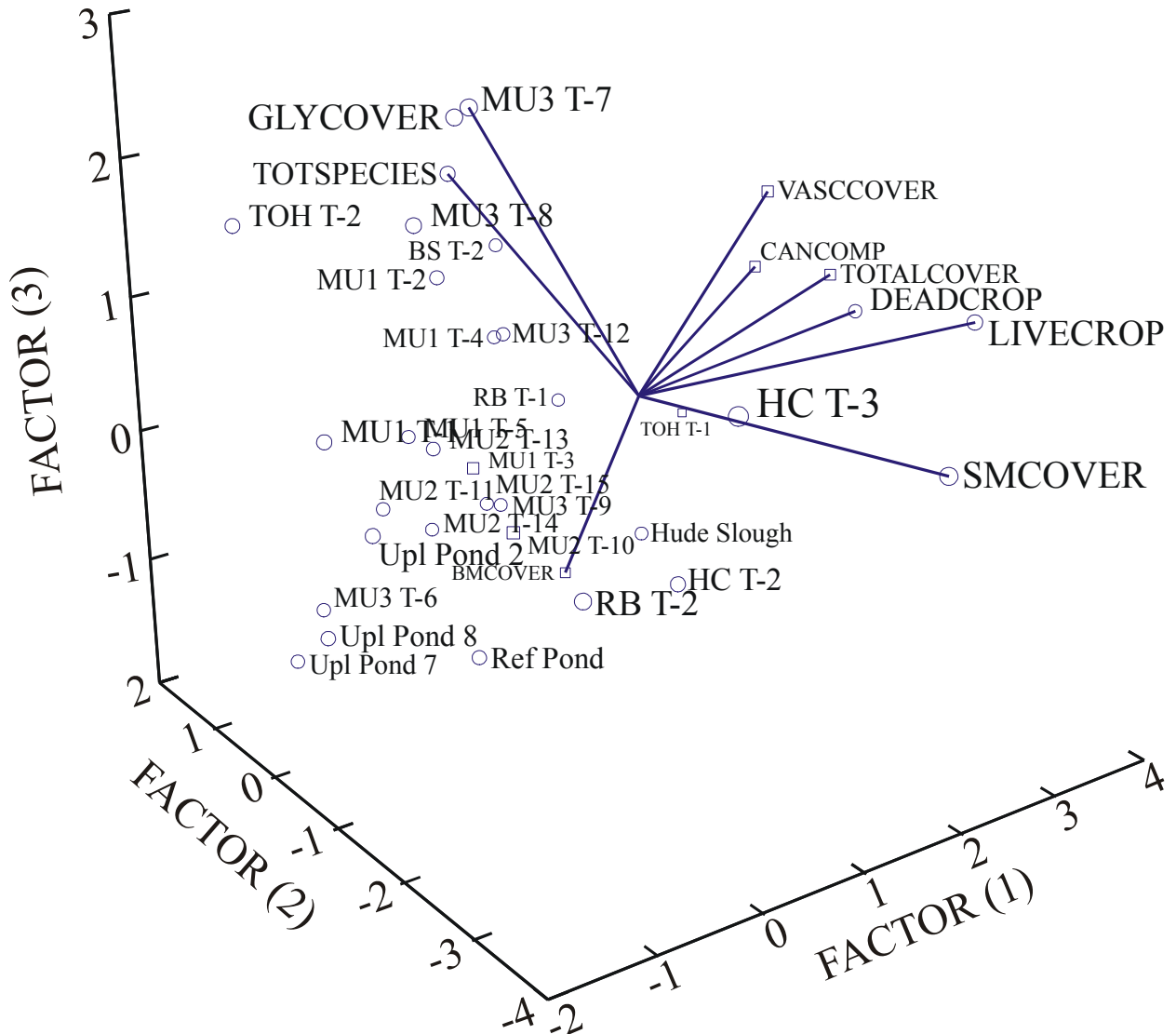
*Species Richness.* While vegetation and vascular plant cover might have been low in Seasonal Ponds, the number of plant species present in areas that did support vegetation was high (Figure 22). Species richness in Seasonal Ponds averaged  $13.0 \pm 4.0$  species (Figure 22). In comparison, species number within the other monitoring units appeared to be reasonably similar, ranging from  $4.0 \pm 0.0$  in the unmanaged Diked Marsh to  $9.4 \pm 0.9$  in the Reclaimed Water monitoring unit (Figure 22).

*Peak Crop.* Again, the unmanaged Diked Marsh and Undiked Marsh surpassed the other monitoring units, at least in live peak crop and total peak crop production. Total amount of live and dead plant material produced for both monitoring units averaged around  $126.3 \pm 0$  grams/dm<sup>2</sup>, approximately 60 grams higher than any other monitoring unit (Figure 22). The next highest monitoring unit in terms of total peak crop was Passive Hydrologic Management ( $64.0 \pm 13.2$  grams/dm<sup>2</sup>), followed by Reclaimed Water + Muted Tidal ( $44.1 \pm 4.4$  grams/dm<sup>2</sup>) and Reclaimed Water ( $39.4 \pm 6.1$  grams/dm<sup>2</sup>; Figure 22). A similar pattern was observed for live peak crop, with Undiked Marsh and Diked Marsh again the leading producers, averaging approximately 100 grams/dm<sup>2</sup> of live material. With very similar biomass values, Reclaimed Water + Muted Tidal and Passive Hydrologic Management appear to fall a collective third ( $\sim 40$  grams/dm<sup>2</sup>; Figure 22). The pattern shifted somewhat for peak dead crop, with unmanaged Diked Marsh ( $29.3 \pm 0$  grams/dm<sup>2</sup>) and Passive Hydrologic Management ( $28.0 \pm 8.2$  grams/dm<sup>2</sup>) generating the most detritus and Seasonal Ponds ( $4.8 \pm 4.8$  grams/dm<sup>2</sup>), Reclaimed Water + Muted Tidal ( $4.7 \pm 2.3$  grams/dm<sup>2</sup>), and Muted Tidal ( $6.5 \pm 5.0$  grams/dm<sup>2</sup>), the least (Figure 22).

*Principal Components Analysis.* Indirect ordination using vegetation variables in a PCA generated even less separation between sampling locations than the soil PCA (Figure 23). Rotation did not simplify structure of the component loadings, so the unrotated model was used. The first axis (PC1) accounted for 35.9 percent of the total variance and appeared to be related to plant cover/biomass, with strong ( $>0.656$ ) positive loadings occurring for total cover, vascular plant cover, canopy complexity, live peak crop, and dead peak crop. The second (PC2) and third (PC3) axes explained much less of the variation in the model, 23.9 and 20.5 percent, respectively. The most significant (negative) loading on PC2 came from percent cover of salt marsh species ( $-0.918$ ), with moderate, positive loadings for cover of brackish marsh species ( $0.558$ ) and live peak crop ( $0.551$ ). Cover of brackish marsh species loaded more strongly on PC3 ( $-0.800$ ), along with cover of glycophytic species ( $0.839$ ) and species richness ( $0.571$ ). Based on these loadings, PC2 would appear to represent the gradient from salt to brackish marsh, while PC3 would represent a brackish to freshwater marsh gradient. In general, these components seemed to clearly separate only those sampling locations that were dominated by salt marsh plant species, regardless of whether these areas were managed or unmanaged (e.g., HC T-2, MU2 T-10, Hude Slough, TOH T-1, MU2 T-15, and BS T-2; Figure 23).

# Principal Components Analysis

## Vegetation Model



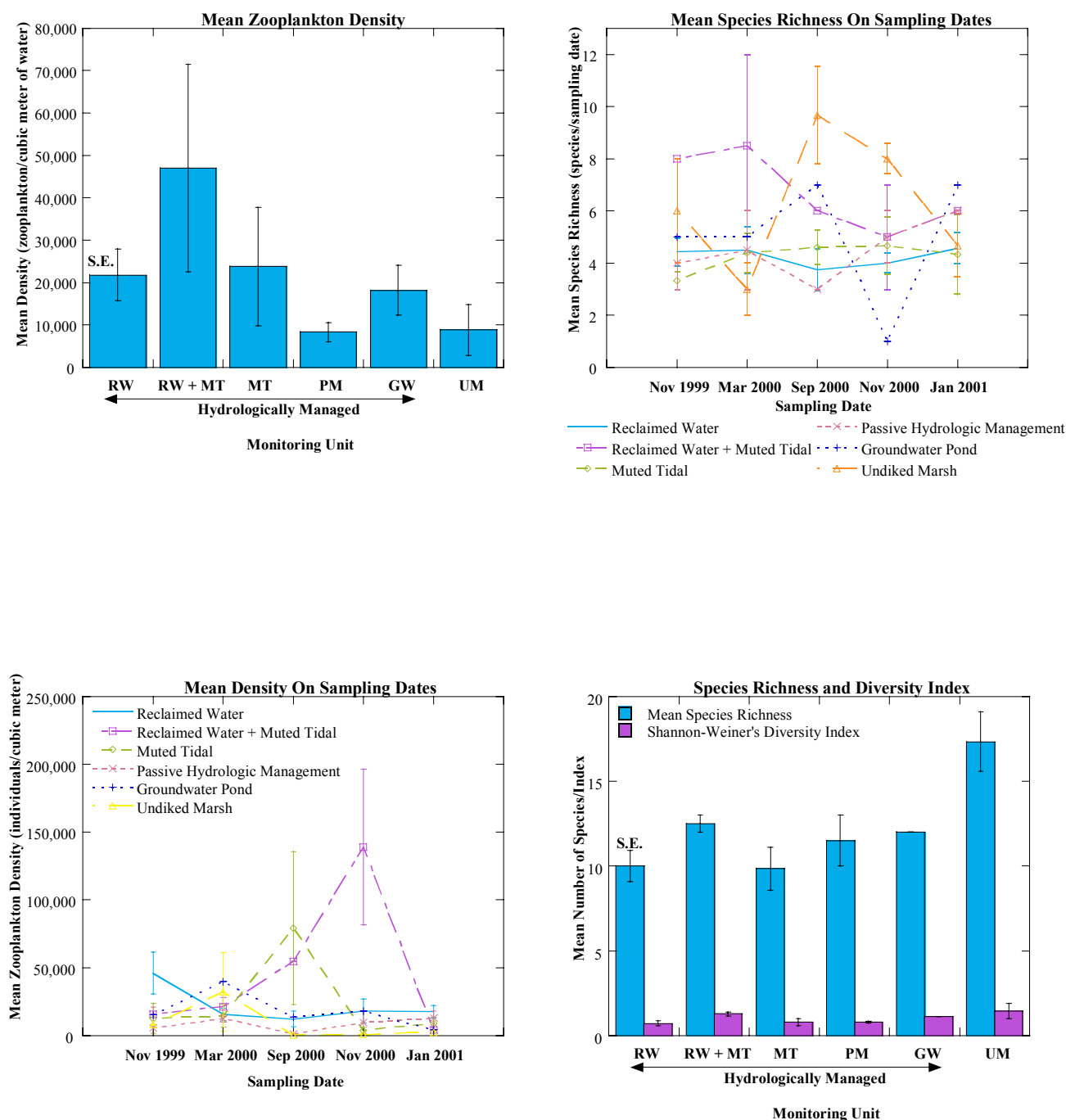
**Figure 23.** Three principal component factors and structure of sampling locations using vegetation-related variables. Variations in font size of the point and axes labels are meant to show differences in position along the Factor 2 axis. This indirect ordination method produced little separation between sample locations. The first axis (**Pc1**) appeared to be related to plant cover/biomass, while the second and third appeared to represent the gradient from salt to brackish marsh and brackish marsh to freshwater marsh, respectively. These components seemed to clearly separate only those sampling locations that were dominated by salt marsh species, regardless of hydrologic management regime.

## Zooplankton

*Density and Species Richness.* The amount of variability in the data seems to preclude making any definitive conclusions about zooplankton abundance. While it appeared that the Reclaimed Water + Muted Tidal monitoring unit had the highest mean density of zooplankton organisms ( $46,999.7 \pm 24,501$  individuals/m<sup>3</sup>), this high mean appeared to be driven to a large extent by elevated numbers during the November 2000 sampling period (Figure 24). The same holds true, to some extent, for the Muted Tidal ( $23,787.8 \pm 14,001.8$  individuals/m<sup>3</sup>) and Reclaimed Water ( $21,808.6 \pm 6,118.3$  individuals/m<sup>3</sup>) monitoring units, both of which had surges in numbers during the September 1999 and November 1999 sampling periods, respectively (Figure 24). These sampling events coincided with periods when Muted Tidal and Reclaimed Water monitoring units were flooded by either tidal flow or reclaimed water to attract waterbirds. Low zooplankton densities reported for the Reclaimed Water monitoring unit in November 2000 appeared to be driven principally by very low numbers in one of the Reclaimed Water monitoring sub-units. Mean zooplankton densities averaged  $190.3 \pm 20.9$  individuals per cubic meter of water in MU1 in November 2000, compared to  $47,100.7 \pm 7,948.6$  in an ecologically similar monitoring subunit (MU3) during the same period and  $91,789.6 \pm 31,450.8$  in MU1 the year prior (November 1999). While less dramatic than that of some of the other monitoring units, the Undiked Marsh ( $8,856.1 \pm 5,987$  individuals/m<sup>3</sup>) and Groundwater Pond ( $18,196.2 \pm 5,891.6$  individuals/m<sup>3</sup>) monitoring units also displayed some seasonal variation, with small increases in numbers in March 2000 (Figure 24).

While the Reclaimed Water + Muted Tidal may have generated the highest mean densities of zooplankton, the highest mean number of species ( $17.3 \pm 1.8$  species/sampling period) and species diversity as measured by the Shannon-Wiener Diversity Index ( $H' = 1.439 \pm 0.45$ ) occurred in the Undiked Marsh monitoring unit (Figure 24). Species richness within other monitoring units appeared relatively similar, ranging from  $9.8 \pm 1.3$  species in the Muted Tidal monitoring unit to  $12.5 \pm 0.5$  species in the Reclaimed Water + Muted Tidal monitoring unit (Figure 24). Results differed somewhat when viewed on the basis of species diversity, with the lowest  $H'$  ( $0.71 \pm 0.14$ ) occurring in the Reclaimed Water monitoring unit and the second highest ( $1.278 \pm 0.11$ ) in the Reclaimed Water + Muted Tidal unit (Figure 24). Groundwater Pond actually exhibited the third highest mean species richness ( $12.0 \pm 0$ ) and species diversity ( $1.12 \pm 0.00$ ; Figure 24).

Seasonal variation in species richness also showed some contrasting patterns between monitoring units. The highest number of species in the Reclaimed Water + Muted Tidal monitoring unit was found between November 1999-March 2000 (Figure 24). Conversely, the highest number of species in the Undiked Marsh and Groundwater Pond monitoring units occurred in September 2000 and, again for the Groundwater Pond unit, in January 2001 (Figure 24). Species richness remained relatively consistent between sampling periods for the Reclaimed Water, Muted Tidal, and Passive Hydrologic Management monitoring units (Figure 24).

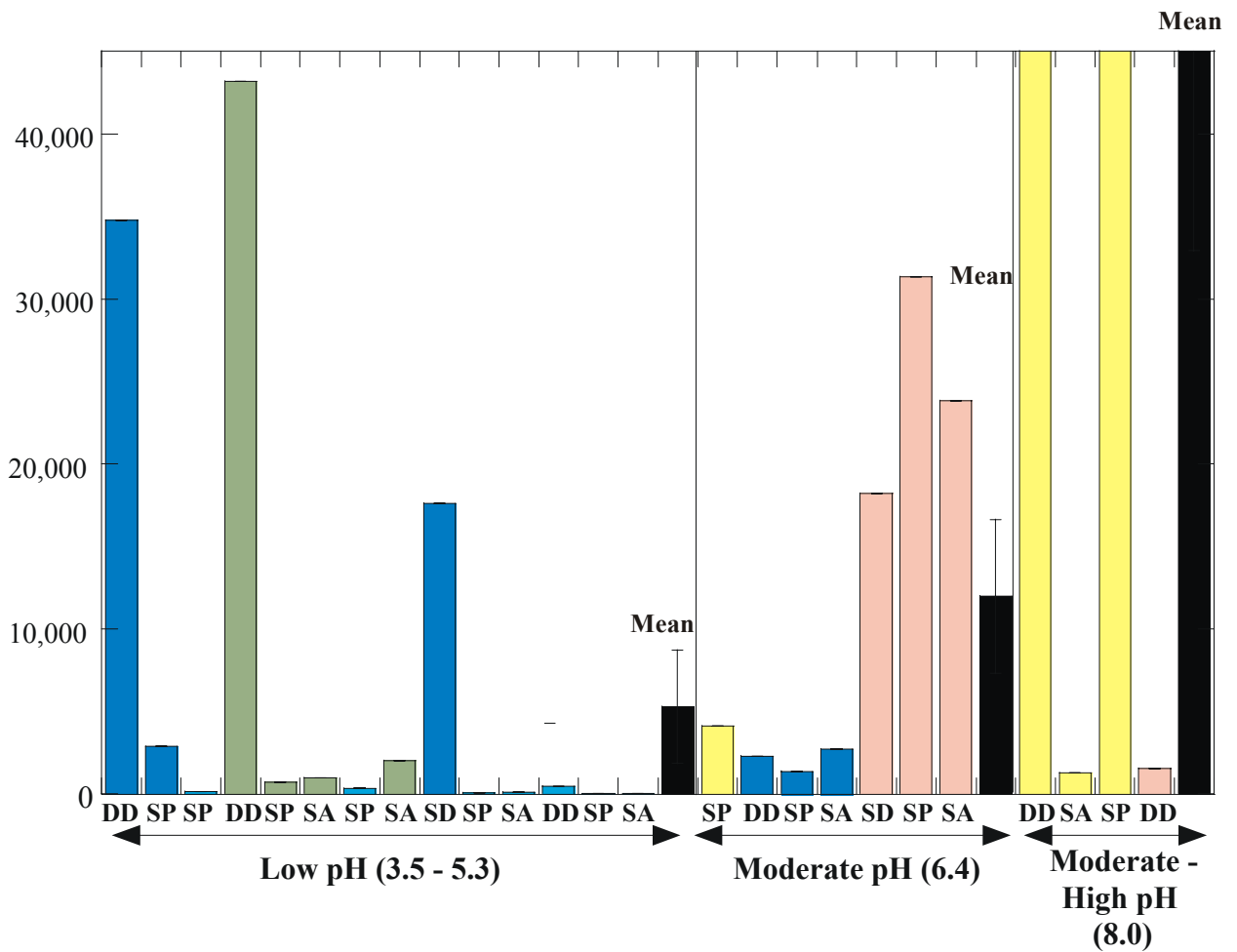


**Figure 24.** Density, species richness, and species diversity of zooplankton in waters of Hudeman Slough Case Study monitoring units. Bars indicate standard error of the mean for sampling locations within monitoring units, when multiple sampling locations were present. (RW-reclaimed water; RW+MT-reclaimed water plus muted tidal; MT-muted tidal; PM-passive management; GW-groundwater pond; UM-undiked marsh)

*Acidification and Density.* Increasing acidification of waters (pH <6) did not show a clear association with decreased densities of zooplankton, although several of the sampling locations with low pH had undeniably low zooplankton densities (Figure 25). Results suggest that, while acidification may affect densities, other factors such as hydrologic regime or season interact to a large enough degree to obscure the relationship. It should be noted that, with reintroduction of tidal flushing and an increase of pH from 3.5 to 7.5, densities of zooplankton in one of the shallowly flooded panne areas jumped from 104.7 to 107,753.5 individuals per cubic meter of water (Figure 25).

*Community Composition.* Hydrologically managed monitoring units displayed different patterns in composition of the zooplankton community than did the unmanaged units. A complete list of all species, genera, and/or orders observed is provided in Table 7. Generally, the hydrologically managed monitoring units were characterized by a community dominated by the order Cyclopidae. Mean densities of Cyclopidae in hydrologically managed monitoring units ranged from 3,551.4/m<sup>3</sup> in Reclaimed Water + Muted Tidal to 16,801.4 individuals/m<sup>3</sup> in Reclaimed Water (Figure 26). The unmanaged monitoring unit, specifically Undiked Marsh, supported many of the same organisms as unmanaged units, but often in lower numbers, and the dominant organism was not Cyclopidae (358.9 individuals/m<sup>3</sup>), but the species, *Eurytemora affinis* (4,301.3 individuals/m<sup>3</sup>; Figure 26). The presence of *Eurytemora affinis* was generally limited to units with some degree of tidal influence (e.g., Undiked Marsh, Reclaimed Water + Muted Tidal, Muted Tidal; Figure 26; Table 7). In fact, *Eurytemora* was actually the dominant organism present in the Reclaimed Water + Muted Tidal monitoring unit, with densities higher than in unmanaged tidal areas (26,032.0 individuals/m<sup>3</sup>; Figure 26). Several other organisms also appear to be tidally influenced, either occurring only in units with tidal influence or only in very low numbers in non-tidal units. Among these were *Acartia tonsa*, *Brachyura*, *Diaphanosoma*, *Cirripida*, *Hydra medusae*, *Mysidacea marinus*, *Toratanus*, *Pseudodiaptomus marinus*, *Oithona*, and *Cumacea* (Figure 26; Table 7).

The order Daphniidae represented the second most common organism in most of the hydrologically managed monitoring units (Figure 26). The Reclaimed Water + Muted Tidal monitoring unit again proved the exception, with Harpacticoida being the subdominant organism (11,031.3 organisms/m<sup>3</sup>; Figure 26). The Reclaimed Water + Muted Tidal monitoring unit supported the highest mean densities of not only *Eurytemora affinis* and Harpacticoida, but also Copepoda (2,141.6 individuals/m<sup>3</sup>), Ostracoda (932.1 individuals/m<sup>3</sup>), *Diaphanosoma* (59.3 individuals/m<sup>3</sup>), Nematoda (2,007.8 individuals/m<sup>3</sup>), Rotifera (2,939.9 individuals/m<sup>3</sup>), Corixidae (518.2 individuals/m<sup>3</sup>), and Annelida (720.3 individuals/m<sup>3</sup>; Figure 26). Corixidae, an order that is characterized as relatively contamination tolerant, was found in relatively low numbers in the Reclaimed Water monitoring unit (90.1 individuals/m<sup>3</sup>), compared to Reclaimed Water + Muted Tidal (see above), Muted Tidal (366.4 individuals/m<sup>3</sup>), and Passive Hydrologic Management (218.0 individuals/m<sup>3</sup>; Figure 26). Highest mean density of the genus *Diaptomus* occurred in the Undiked Marsh (657.2 individuals/m<sup>3</sup>), with the second highest mean density occurring in the Reclaimed Water monitoring unit (596.0 individuals/m<sup>3</sup>; Figure 26). In addition to Cyclopidae, the Reclaimed Water monitoring unit generated the highest mean densities of Calanoida (274.3 individuals/m<sup>3</sup>; Figure 26). Calanoids were actually observed in very low numbers in all of the monitoring units except Reclaimed Water (Figure 26). It should be noted that, in addition to zooplankton, waters of the Reclaimed Water monitoring unit supported high numbers of a very

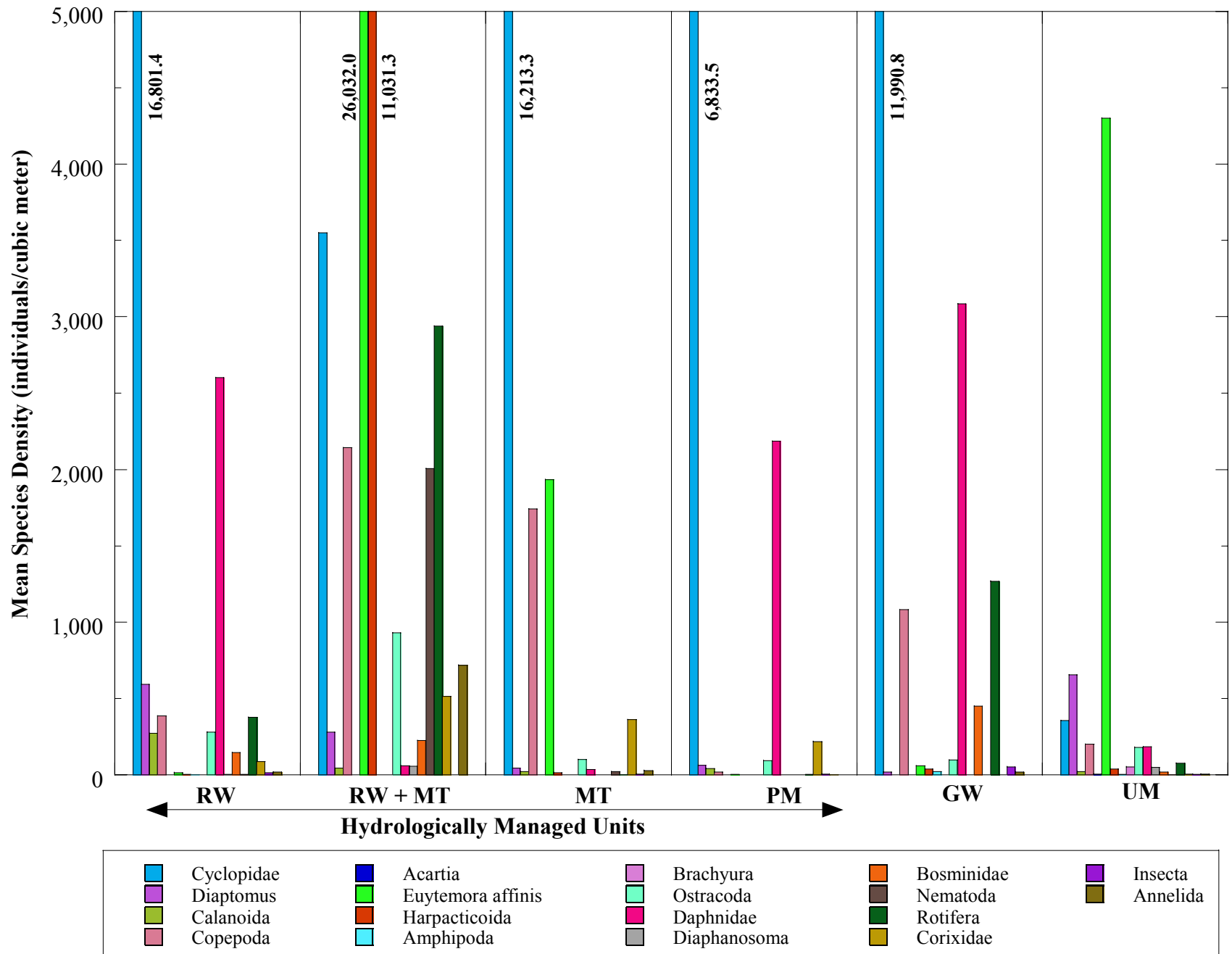


**Figure 25.** Density of zooplankton in waters of sampling locations with varying pH and water depths/hydrologic regime. Season of sampling is indicated by coloring of the bars.

**Table 7.** Zooplankton taxa observed in monitoring units within the Hudeman Slough Enhancement Wetlands Case Study area.

PHYLUM, SUBPHYL, <b>Class</b> , <b>Order</b> , Family, Genus or Species or Life Stage (Hydra only) <sup>1</sup>	Reclaimed Water	Reclaimed+ Muted Tidal	Muted Tidal	Passive Mgt	Groundwater Pond	Undiked Marsh
ANNELIDA	✓	✓	✓	✓	✓	✓
ARTHROPODA						
<b>Arachnida</b>	✓		✓	✓		
<b>Insecta</b>	✓		✓	✓	✓	✓
Corixidae	✓	✓	✓	✓		✓
CRUSTACEA						
<b>Branchiopoda</b>						
Bosminidae	✓	✓			✓	✓
Daphniidae	✓	✓	✓	✓	✓	✓
Sididae						
<i>Diaphanosoma</i>	✓	✓				✓
<b>Malacostraca</b>						
<b>Amphipoda</b>	✓			✓		✓
<b>Cumacea</b>						✓
<b>Mysidacea</b>						
<i>Mysidacea marinus</i>			✓			✓
<b>Copepoda</b>	✓	✓	✓	✓	✓	✓
<b>Calanoida</b>	✓	✓	✓	✓		✓
<i>Acartia tonsa</i>						✓
<i>Diaptomus</i>	✓	✓	✓	✓	✓	✓
<i>Eurytemora affinis</i>	✓	✓	✓	✓	✓	✓
<i>Pseudodiaptomus marinus</i>						✓
<i>Toratanus</i>						✓
<b>Cyclopoida</b>	✓	✓	✓	✓	✓	✓
<i>Oithona</i>						✓
<b>Harpacticoida</b>	✓	✓	✓		✓	✓
<b>Ostracoda</b>	✓	✓	✓	✓	✓	✓
<b>Decapoda</b>						
<b>Brachyura</b>						✓
<b>Cirripida</b>						✓
CNIDARIA						
HYDRA						
medusae						✓
polyps	✓			✓		
MOLLUSCA						
GASTROPODA			✓	✓		
NEMATODA	✓	✓	✓			✓
ROTIFERA	✓	✓	✓	✓	✓	✓

<sup>1</sup> Organisms not identified to genus or species were lumped into next higher taxa classification.



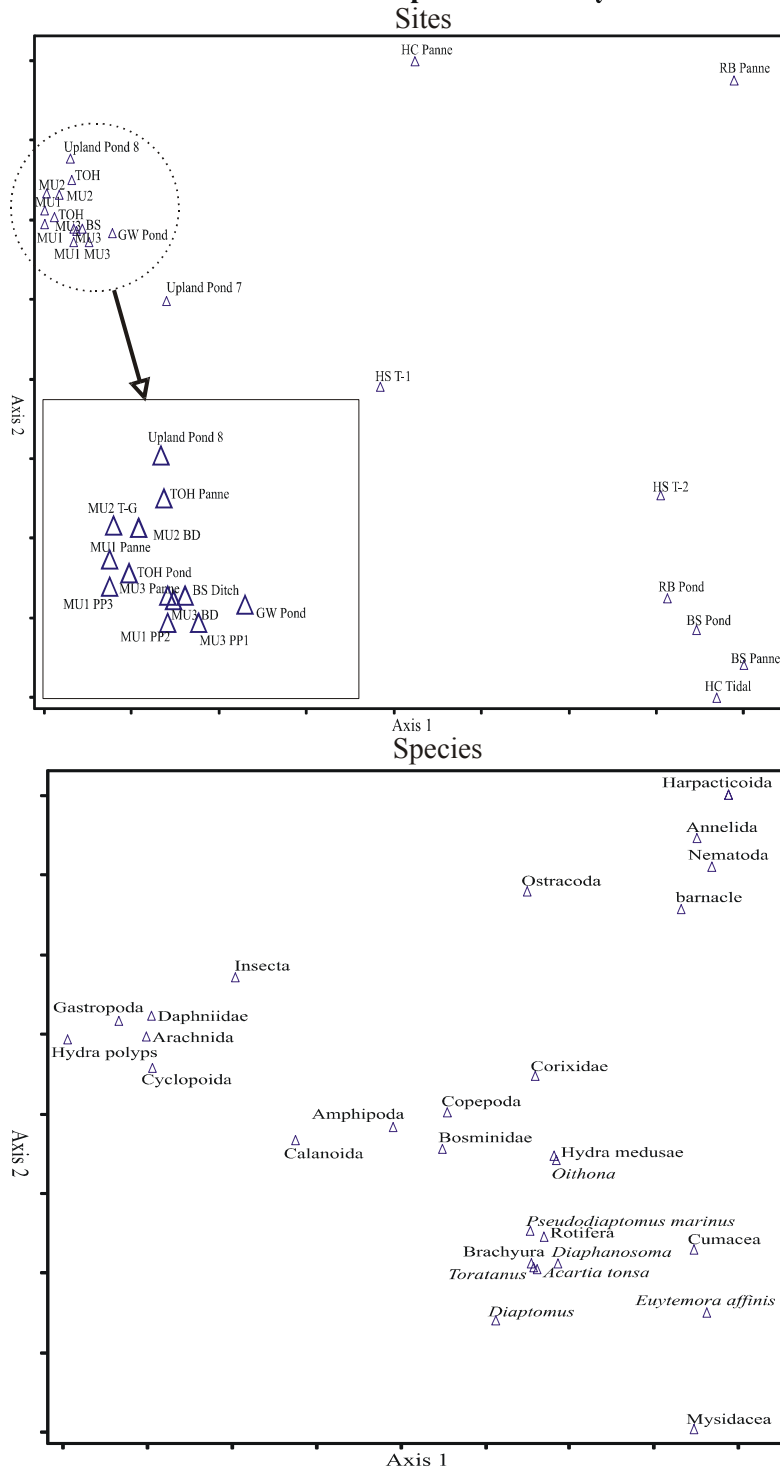
**Figure 26.** Densities of the most common zooplankton taxa in waters of the Hudeman Slough Case Study monitoring units.

large dinoflagellate (*Ceratium*; Table 6; Sean Avent, invertebrate biologist, San Francisco State University, *pers. comm.*).

*Detrended Correspondence Analysis.* Indirect ordination using zooplankton species in a DCA produced some separation between sampling locations (Figure 27). Undiked Marsh and selected managed Muted Tidal sampling locations that were more tidally influenced generally fell outside a very tight cluster of sampling locations that included all managed Reclaimed Water, Passive Hydrologic Management, Groundwater Pond, and two of the Muted Tidal sampling locations that receive minimal tidal influence. The one anomaly came from a created pond that is perennially inundated with reclaimed water: it fell slightly outside the tight cluster and is not influenced at all by tides. The variance, as indicated by the eigenvalues, explained by the axes in Figure 27 was 0.783 (axis I) and 0.250 (axis II). Results from the DCA confirmed the general trend observed in species composition for most of the managed units in that the tight cluster of sampling locations was generally distinguished by the presence of taxa such as Cyclopidae and Daphniidae, as well as Hydra polyps, Gastropoda, Arachnida, and Insecta. Most of the tidally influenced sampling locations fell toward the lower right-hand corner of Figure 27, which corresponded generally with the presence of taxa that were either numerically dominant (e.g., *Eurytemora affinis*) or only present in tidally influenced areas (*Mysidacea marinus*, *Diaphanosoma*, Cumacea, Brachyura, *Acartia tonsa*, *Pseudodiaptomus marinus*). One each of the Reclaimed Water + Muted Tidal and Muted Tidal sampling locations grouped toward the upper right-hand corner of Figure 27, probably based on comparatively higher densities of Harpacticoida, Ostracoda, and Nematoda relative to other sampling locations of the same type. Separation of HS T-1 from other Undiked Marsh sampling locations remains harder to understand, but may be linked to lower densities of Copepoda and higher densities of Bosminidae relative to other tidal sampling locations.

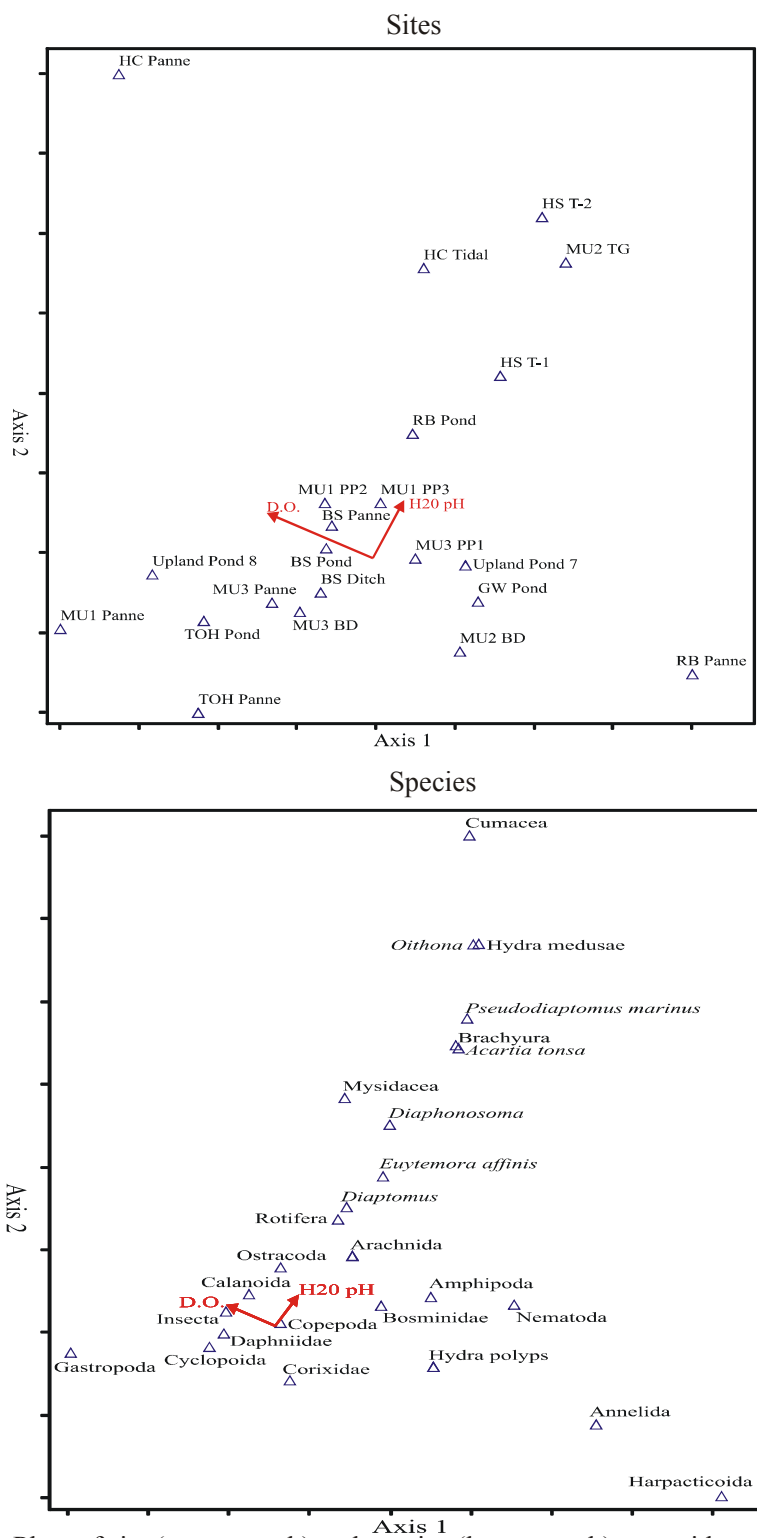
*Canonical Correspondence Analysis.* Direct ordination using zooplankton species and environmental variables resulted in a slightly greater degree of separation between sampling locations than did indirect ordination using DCA. Axis I (Eigenvalue=0.392) explained 20.7 percent of species variation related to primarily water D.O. and possibly water temperature (indicated by environmental vectors at acute angles to Axis I in Figure 28). Further separation was provided by Axis II (Eigenvalue=0.280), which explained 14.8 percent of the species variation related primarily to water pH and possibly D.O. Vectors point toward increasing values for an environmental variable, with a longer vector indicating greater range of variation of a variable, as well as greater range in species distributions for the variable, along the canonical axis. Therefore, length of the vector arrow relates to importance of the variable, while the acuteness of the angle between the vector arrow and the axis represents the degree of correlation between those two. Distribution of sampling locations with elevated D.O. and comparatively lower water temperatures and pH corresponded to those on the lower left-hand side of Figure 28. These sampling locations, which included Reclaimed Water, Reclaimed Water + Muted Tidal, Muted Tidal, Passive Hydrologic Management, and Groundwater Pond monitoring units, were characterized by taxa such as Gastropoda, Cyclopidae, Daphniidae, Insecta, Copepoda, Calanoida, and Ostracoda (Figure 28). More moderate D.O., temperature, and pH conditions were generally associated with sampling locations that were either tidal or tidally influenced (e.g., HS T-2, HC Tidal, and possibly HS T-1), as well as a Passive Hydrologic Management sampling locations (MU2 TG; Figure 28). Species with optima in moderate D.O., temperature,

## Detrended Correspondence Analysis



**Figure 27.** Plot of site scores (upper graph) and species centroids (lower graph) on the first two axes for the detrended correspondence analysis of zooplankton species composition and abundance. This indirect ordination method produced some separation between sampling locations, with most of the managed sampling locations receiving no to minimal tidal influence clustering very tightly (see circled locations and inset box). As the lower graph indicates, these non- to micro-tidal managed sampling locations were distinguished by a characteristic species assemblage dominated by taxa such as Cyclopidae, Daphniidae, as well as Hydra polyps, Gastropoda, Arachnida, and Insecta.

# Canonical Correspondence Analysis



**Figure 28.** Plots of site (upper graph) and species (lower graph) centroids on the first two canonical axes for the correspondence analysis of zooplankton and environmental variables such as temperature, salinity, pH, and dissolved oxygen (D.O.). Arrows represent direction of increasing value for environmental variables, and more acute angles between arrow and axis indicate stronger correlation of variables with the axis.

and pH conditions included most of the species that occurred either exclusively or principally in tidally influenced areas, as well as Amphipoda, Nematoda, and Hydra polyps (Figure 28). Two sampling locations appeared to be separate from either of these two groups. Low D.O. with high water temperatures and pH was represented by a single sampling location (RB Panne), part of the Reclaimed Water + Muted Tidal monitoring unit, and seemed associated with the presence of Harpacticoida and possibly Annelida. Conversely, high D.O., lower water temperatures, and high pH was represented by a Muted Tidal sampling location (HC Panne).

### **Zoo Benthos, Epibenthos, and Benthic Infauna**

Densities of benthic invertebrates within sediment cores were extremely low. Anywhere from 40 to 50 percent of the samples had no organisms during each sampling period, and organisms were never detected in at least five (5) of the 20 sampling locations. Both the low total numbers and low numbers of species observed in sediment cores probably resulted from the anoxic nature of the frequently flooded dense clay soils. Many of the organisms found in sediment samples represented larval (puparium) stages of organisms such as Diptera or resting stages or exoskeletons of organisms found in the water column (i.e., Copepoda orders such as Calanoida, Harpacticoida, and Ostracoda; Table 8). While benthic species diversity remained generally low, the highest number of taxa did actually occur in hydrologically managed monitoring units receiving reclaimed water, with Reclaimed Water having nine (9) taxa and Reclaimed Water + Muted Tidal, five (5) taxa (Table 8). The lowest number of orders or suborders was recorded in the Passive Hydrologic Management and Groundwater Pond monitoring units, which had two (2) and three (3) taxa, respectively (Table 8).

The most abundant organisms at sampling locations in monitoring units receiving reclaimed water were Ephydriidae (Diptera: shore and brine flies), Sciomyzidae (Diptera; *Sepedon*; marsh flies), Oligochaeta (f. Tubificidae; blood worms), and Copepoda order Calanoida (Table 8). Most of these taxa were locally abundant at certain sampling locations, but absent or undetected at others. Tubificidae was the only organism that occurred at multiple reclaimed water sampling locations. Tubificidae have been generally classified as contamination tolerant indicators (Canfield et al. 1994 and 1996). For San Francisco Bay, benthic communities in which oligochaetes contribute more than 50 percent of total abundance may fall outside “ambient” reference conditions and therefore point to a higher degree of contamination at the sampling location (Lowe and Thompson 1999). As noted in the Methods, we did not calculate actual densities, but qualitatively estimated abundance of benthic organisms. Based on these estimations, oligochaetes did represent more than 50 percent of the total abundance of benthic organisms *in samples that had organisms*. Numbers averaged around 110 in Reclaimed Water monitoring unit, with one sample having as many as 425 blood worms. While these results imply that sediment in the Reclaimed Water monitoring unit may be ecologically impacted, it should be noted that Tubificidae were found in at least one of the three Reclaimed Water monitoring sub-units only during one sampling period, and the numbers were very low (13). Furthermore, this same sub-unit also consistently supported *Hyalella azteca* (Table 8), a member of Amphipoda that has been described by Lowe and Thompson (1999) as a contamination intolerant indicator.

**Table 8.** Zoobenthos, epibenthos, and infauna taxa observed during the Hudeman Slough Case Study.

PHYLUM, SUBPHYLUM, Class, Order, Family, Genus or Species <sup>1</sup>	Reclaimed Water	Reclaimed + Muted Tidal	Muted Tidal	Passive Mgt	Groundwater Pond	Undiked Marsh
<b>ANNELIDA</b>						
<b>Oligochaeta</b>						
Enchytraeidae	√E	√E				
Naididae						
<i>Chaetogaster</i>	√E,B					
Tubificidae	√B	√B	√B	√B		√B
<b>ARTHROPODA</b>						
<b>Arachnida</b>	√E					
<b>Insecta</b>						
<b>Coleoptera</b>		√E				
Dytiscidae						
<i>Rhantus</i>		√E				
Hydrophilidae						
<i>Enochrus</i>	√E					
<b>Diptera</b>						
Chironomidae	√E	√E,B	√B		√B	
Ephydriidae						
<i>Ephydra</i>	√E,B	√B	√B		√B	
<i>Notiphila</i>	√E					
<i>Parydra quadrituberculata</i>		√E	√B			
Sciomyzidae						
<i>Sepedon</i>	√B	√B				
Simuliidae	√E					
Tabanidae						
<i>Tabanus</i>	√E					
Tipulidae						
<i>Limnophila</i>	√B			√B		
<b>Ephemeroptera</b>						
Ephemerellidae						
<i>Ephemerella</i>	√E					
<b>CRUSTACEA</b>						
<b>Branchiopoda</b>						
Daphniidae	√E					
<i>Daphnia</i>	√E					
<b>Malacostraca</b>						
<b>Amphipoda</b>						
<i>Corophrium spinicorne</i>						√B
Gammaridae						
<i>Gammarus</i>	√E					
Hyalellidae						
<i>Hyalella azteca</i>	√E,B					
<b>Decapoda</b>						
Palaemonidae						
<i>Palaemonetes</i>						√B
<b>Copepoda</b>	√E					
<b>Calanoida</b>	√E,B					
<b>Cyclopoida</b>	√E					
<b>Harpacticoida</b>	√B	√E,B				
<b>Ostracoda</b>	√E,B	√E				

<b>Table 8 (cont').</b> Zoobenthos, epibenthos, and infauna taxa observed during the Hudeman Slough Case Study.						
PHYLUM, SUBPHYLA, <b>Class, Order,</b> Family, <i>Genus</i> or <i>Species</i> <sup>1</sup>	Reclaimed Water	Reclaimed + Muted Tidal	Muted Tidal	Passive Mgt	Groundwater Pond	Undiked Marsh
<b>MOLLUSCA</b>						
GASTROPODA						
Assiminidae						
<i>Assiminea californica</i>	√E,B				√B	
Hydrobiidae						
<i>Amnicola</i>		√E				
Physidae						
<i>Physella</i>	√E					
BIVALVIA						
Sphaeriidae						
<i>Pisidium</i>						√B
<b>NEMATODA</b>	√E					
<b>ROTIFERA</b>		√E				

<sup>1</sup> Organisms not identified to genus or species were lumped into next higher taxa classification. Codes refer to whether organisms found in epibenthos samples (E) or benthic sediment samples (B). Shading refers to organisms that were abundant (>30 per sample) during most or all of the sampling periods.

Tubificidae were also present in other monitoring units, including Muted Tidal and one of the Undiked Marsh sampling locations (Table 8). The widespread distribution of Tubificidae within diked and undiked areas may relate to the fact that, within San Francisco Bay, Tubificidae is considered a more common and abundant species in the estuarine benthic assemblages than the fresh brackish ones (Lowe and Thompson 1999). Numbers of Tubificidae in the Undiked Marsh sampling location near Hudeman Slough ranged from 18 to 123 per sample during the four sampling periods and were therefore generally lower than those in units receiving reclaimed water. However, as with the Reclaimed Water monitoring sub-unit, the Hudeman Slough Undiked Marsh sampling location also consistently supported *Corophium spinicorne*, another member of Amphipoda that has been characterized as a contamination intolerant indicator (Lowe and Thompson 1999). Within San Francisco Bay, *Corophium spinicorne* appears to only occur in the fresh brackish benthic assemblages where salinities are less than 5 practical salinity unit (psu), and the substrate is composed of fine sediments (Lowe and Thompson 1999). In general, species diversity in the Undiked Marsh sampling locations remained low, with a maximum of three taxa (3) per sample found (Table 8). On some sampling dates, certain Undiked Marsh sampling locations had no organisms. According to the RMP indices, unimpacted estuarine sampling locations generally support anywhere from four (4) to 22 taxa, with a mean of 11 (Lowe and Thompson 1999).

Blood worms occurred only once in the Muted Tidal monitoring unit, and numbers were low (32 per sample; Table 8). However, species richness and organism abundance within the Muted Tidal monitoring unit were low in general (Table 8). Most of the sampling locations had no organisms in any of the sampling periods. The one sampling location in which organisms were found typically supported taxa such as *Ephydra* sp. (Diptera; Ephydriidae; shore and brine flies) and *Parydra quadrituberculata* (Diptera; Ephydriidae), with members of Tubificidae (Oligochaeta) and Chironomidae (Diptera) found just once each and in low numbers (Table 8). Chironomids are restricted to freshwater (<2 psu) and are therefore members of the fresh brackish assemblage (Lowe and Thompson 1999). Abundances of this aquatic insect are believed to increase with increased contamination (Canfield et al. 1994 and 1996). Chironomids

were also observed in the Reclaimed Water + Muted Tidal and Groundwater Pond monitoring units. Numbers in these monitoring units ranged from 18 (Reclaimed Water + Muted Tidal) to 189 (Groundwater Pond) chironomids per sample. Interestingly, while Reclaimed Water monitoring units would be classified as fresh-brackish marsh communities, chironomids were not found in this monitoring unit on any of the sampling dates (Table 8).

While the epibenthos was not formally sampled, haphazard sampling of macroalgae and emergent vegetation suggested that species richness and abundance within the epibenthic community may exceed that of the benthic infauna. Organisms collected comprised a mixture of oligochaetes, water mites, insects, nematodes, water fleas (*Daphnia*), amphipods (e.g., *Gammarus*), and copepods (Table 8). As many of the emergent vegetation sampling locations were in open waters, it is likely that some of these taxa such as copepods were in the waters near the vegetation, not necessarily on the vegetation itself. Particularly numerous were members of Gastropoda, specifically *Assiminea californica*, a snail characterized as being abundant in pickleweed marshes (Table 8). At one point, densities of *Assiminea* on emergent spikerush (*Eleocharis macrostachya*) in one of the Reclaimed Water monitoring sub-units reached as high as 1.6 snails/cm<sup>2</sup>. Other gastropods observed in monitoring units, although not necessarily in high numbers, were *Physella* and *Amnicola* (Table 8).

### **Avian Surveys**

Appendix C provides a complete list of avian species observed during the monitoring study. Results are first presented by study period, then for the entire monitoring study.

#### ***Species Richness and Diversity By Study Period***

*Open Water.* Mean species richness was highest in the Reclaimed Water monitoring units during the September-October study period (Table 9). Shallow probers were the dominant waterbirds observed in OF2 during the study period, representing 50 percent of the waterbird species observed (Figure 29). Shallow probers and dabblers each comprised 43 percent of waterbirds observed in Reclaimed Water study plot MU3-9. Overall, species diversity (1/D and H') was comparable between the Reclaimed Water and Seasonal Ponds when considering all species observed. No waterbirds were observed in the Seasonal Ponds during this period.

During the November-April period, mean waterbird species richness in Reclaimed Water study plot MU3-9 was more than double the other study plots (Table 10). The remaining Open Water units were comparable. The majority of waterbird species observed in MU3-9 were dabblers (37 percent, Figure 29). Species from each waterbird foraging guild were observed in the Reclaimed Water study plots; however, no sweeper/surface feeders or piscivores were observed in the Seasonal Ponds.

Mean waterbird species richness for the May-August study period in Reclaimed Water study plot MU3-9 was again more than double that of the other study plots (Table 11), with dabbler species the most dominant (68 percent of waterbirds observed, Figure 29). However, species diversity results for all species observed and waterbirds alone were comparable between sites.

**Table 9.** Mean (standard error) avian species richness and species diversity in Open Water habitats during September-October, 1999-2000.

Variable	Reclaimed Water		Seasonal Ponds	
	OF2 <sup>a</sup>	MU3-9 <sup>b</sup>	MU3-10 <sup>b</sup>	DFG-13 <sup>b</sup>
<b>All Birds</b>				
Species Richness	11.0 (2.7)	4.5 (3.0)	2.5 (1.3)	3.3 (1.3)
Simpson's <sup>c</sup>	3.8 (3.2)	2.0 (2.7)	1.7 (1.2)	3.0 (2.0)
Shannon-Wiener <sup>d</sup>	0.6 (0.3)	0.5 (0.2)	0.3 (0.2)	0.4 (0.1)
<b>Waterbirds</b>				
Species Richness	2.7 (1.5)	1.8 (2.2)	0.0	0.0
Simpson's <sup>c</sup>	4.6 (5.1)	0.5 (0.9)	-	-
Shannon-Wiener <sup>d</sup>	0.3 (0.3)	0.1 (0.2)	-	-

<sup>a</sup> n=3; <sup>b</sup> n=4;

<sup>c</sup> Simpson's Index of Diversity,  $1/D; D = \sum \frac{n_i(n_i - 1)}{N(N - 1)}$ ;

<sup>d</sup> Shannon-Wiener Diversity Index,  $H' = -\sum p_i \ln p_i$

**Table 10.** Mean (standard error) avian species richness and species diversity in Open Water habitats during November-April, 1999-2001.

Variable	Reclaimed Water		Seasonal Ponds	
	OF2 <sup>a</sup>	MU3-9 <sup>b</sup>	MU3-10 <sup>b</sup>	DFG-13 <sup>b</sup>
<b>All Birds</b>				
Species Richness	5.9 (2.2)	8.9 (2.4)	4.3 (2.2)	4.3 (2.2)
Simpson's <sup>c</sup>	4.0 (3.3)	4.1 (2.2)	3.0 (2.4)	3.4 (1.8)
Shannon-Wiener <sup>d</sup>	0.5 (0.2)	0.7 (0.2)	0.4 (0.2)	0.5 (0.2)
<b>Waterbirds</b>				
Species Richness	1.7 (2.0)	4.6 (1.7)	1.3 (1.1)	1.1 (1.7)
Simpson's <sup>c</sup>	1.3 (1.8)	3.0 (1.6)	1.3 (1.4)	1.3 (2.0)
Shannon-Wiener <sup>d</sup>	0.3 (0.5)	0.5 (0.2)	0.2 (0.2)	0.2 (0.3)

<sup>a</sup> n=11; <sup>b</sup> n=12;

<sup>c</sup> Simpson's Index of Diversity,  $1/D; D = \sum \frac{n_i(n_i - 1)}{N(N - 1)}$ ;

<sup>d</sup> Shannon-Wiener Diversity Index,  $H' = -\sum p_i \ln p_i$

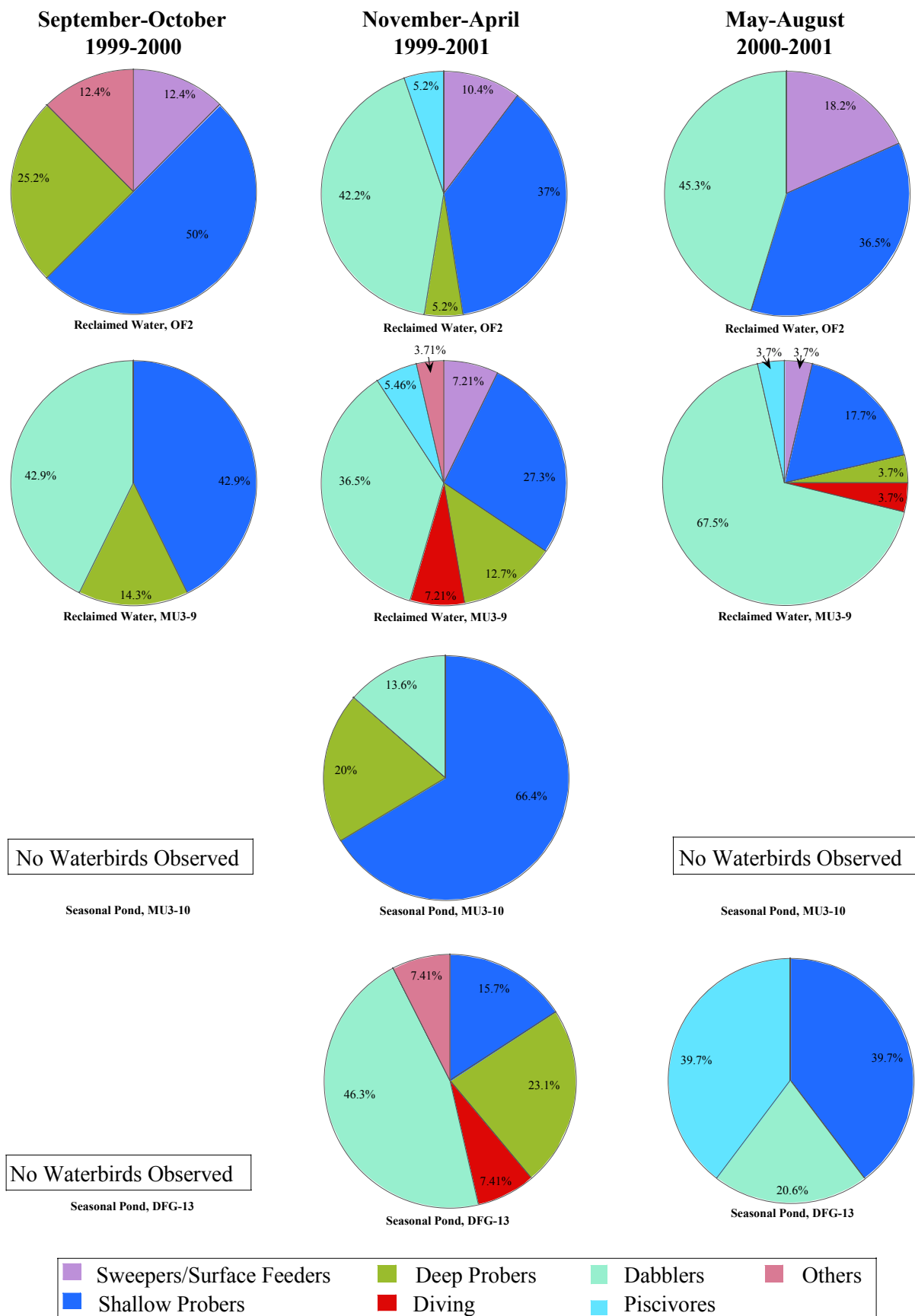
**Table 11.** Mean (standard error) avian species richness and species diversity in Open Water habitats during May-August, 2000-2001.

Variable	Reclaimed Water		Seasonal Ponds	
	OF2 <sup>a</sup>	MU3-9 <sup>a</sup>	MU3-10 <sup>a</sup>	DFG-13 <sup>a</sup>
<b>All Birds</b>				
Species Richness	6.1 (2.4)	8.0 (3.7)	4.1 (2.4)	5.5 (2.4)
Simpson's <sup>b</sup>	3.8 (3.2)	3.9 (2.5)	2.6 (1.5)	3.5 (2.9)
Shannon-Wiener <sup>c</sup>	0.4 (0.1)	0.6 (0.2)	0.4 (0.3)	0.6 (0.2)
<b>Waterbirds</b>				
Species Richness	1.4 (1.7)	3.5 (2.9)	0.0	0.6 (1.2)
Simpson's <sup>b</sup>	1.1 (1.6)	2.5 (2.2)	-	1.1 (2.2)
Shannon-Wiener <sup>c</sup>	0.2 (0.2)	0.3 (0.3)	-	0.1 (0.2)

<sup>a</sup> n=4;

<sup>b</sup> Simpson's Index of Diversity,  $1/D; D = \sum \frac{n_i(n_i - 1)}{N(N - 1)}$ ;

<sup>c</sup> Shannon-Wiener Diversity Index,  $H' = -\sum p_i \ln p_i$



**Figure 29.** Mean waterbird foraging guild species richness in open water habitats during Hudeman Slough Case Study monitoring, 1999-2001.

*Flooded Wetlands.* Mean waterbird species richness during the September-October study period was similar among the Reclaimed Water and Muted Tidal study plots (Table 12). However, the mean waterbird species richness on the Reclaimed Water + Muted Tidal plot was noticeably less. Dabblers were the most observed guild on Reclaimed Water study plots MU1 and MU3-8 (49 and 54 percent of waterbird species observed, respectively, Figure 30). Shallow and deep probers were dominant on the Muted Tidal study plot (42 and 27 percent, respectively). A similar pattern was observed during the November-April and May-August study periods (Tables 13 and 14; Figure 30). Dabblers continued to be the dominant waterbirds observed in the Reclaimed Water study plots, while shallow and deep probers, as well as sweepers/surface feeders, were dominant in the Muted Tidal study plot. Species diversity followed a similar trend, with Reclaimed Water + Muted Tidal results comparable and the Reclaimed Water + Muted Tidal plots less diverse.

### **Densities By Study Period**

*Open Water.* Mean densities within Reclaimed Water study plot OF2 during September-October were skewed by large numbers of red-winged blackbirds (*Agelaius phoeniceus*) and violet-green swallows (*Tachycineta thalassina*). Calculated without blackbirds and swallows, the mean density for all species observed ( $\bar{x}=31.0\pm9.5$ ) in OF2 is more consistent with observations at the remaining Open Water study plots (Table 15). In all study periods, mean waterbird densities were greater in Reclaimed Water study plot MU3-9 than in the remaining study plots (ranging from 13 percent to 100 percent greater, Table 15; Figure 31). Dabblers had the highest numbers in the Reclaimed Water study plot MU3-9 during all study periods ( $\bar{x}=12.8$  birds/plot in September-October,  $\bar{x}=26.7$  birds/plot in November-April, and  $\bar{x}=18.1$  birds/plot in May-August).

*Flooded Wetlands.* Mean densities within MU1 during September-October were also skewed by large numbers of red-winged blackbirds observed within the study plot (Table 16). Without blackbirds, the mean density for all species observed ( $\bar{x}=89.00\pm120.51$ ) is closer to the remaining plots. Waterbirds comprised 81 percent of the birds observed in Reclaimed Water study plot MU3-8 and 80 percent of the birds observed in the Muted Tidal study plot. Waterbird densities were greatest in Reclaimed Water study plot MU3-8, with dabblers (predominately American coot, *Fulica americana*, followed by mallard, *Anas platyrhynchos*, and northern shoveler, *Anas clypeata*) comprising 59 percent of waterbirds observed and shallow probers (mostly western sandpiper, *Calidris mauri*) comprising 38 percent (Figure 32). In the Muted Tidal study plot, shallow probers (mostly western sandpiper) were the dominant waterbirds observed ( $\bar{x}=42.3$  birds/plot). Sweepers/surface feeders (entirely American avocet, *Recurvirostra americana*) were the second most observed guild ( $\bar{x}=14.0$  birds/plot). In Reclaimed Water study plot MU1, dabblers were the dominant waterbirds observed ( $\bar{x}=41.0$  birds/plot).

**Table 12.** Mean (standard error) avian species richness in Flooded Wetlands during September-October, 1999-2000.

Variable	<u>Reclaimed Water</u>		<u>Reclaimed + Muted Tidal</u>	<u>Muted Tidal</u>
	MU1 <sup>a</sup>	MU3-8 <sup>b</sup>	OF1 <sup>b</sup>	DFG-15 <sup>a</sup>
<b>All Birds</b>				
Species Richness	9.0 (4.0)	8.3 (4.7)	8.0 (2.0)	6.5 (3.7)
Simpson's <sup>c</sup>	3.8 (3.2)	2.7 (0.7)	4.7 (1.2)	3.0 (2.0)
Shannon-Wiener <sup>d</sup>	0.6 (0.3)	0.5 (0.1)	0.7 (0.1)	0.5 (0.2)
<b>Waterbirds</b>				
Species Richness	4.6 (1.9)	5.0 (5.0)	1.0 (1.7)	4.8 (3.5)
Simpson's <sup>c</sup>	4.6 (5.1)	1.4 (1.6)	0.6 (1.0)	3.2 (2.3)
Shannon-Wiener <sup>d</sup>	0.3 (0.3)	0.3 (0.3)	0.1 (0.2)	0.4 (0.3)

<sup>a</sup> n=4; <sup>b</sup> n=3;

<sup>c</sup> Simpson's Index of Diversity,  $1/D; D = \sum \frac{n_i(n_i - 1)}{N(N - 1)}$  ;

<sup>d</sup> Shannon-Wiener Diversity Index,  $H' = -\sum p_i \ln p_i$

**Table 13.** Mean (standard error) avian species richness in Flooded Wetlands during November-April, 1999-2001.

Variable	<u>Reclaimed Water</u>		<u>Reclaimed + Muted Tidal</u>	<u>Muted Tidal</u>
	MU1 <sup>a</sup>	MU3-8 <sup>a</sup>	OF1 <sup>b</sup>	DFG-15 <sup>c</sup>
<b>All Birds</b>				
Species Richness	9.3 (3.9)	10.3 (4.3)	7.4 (2.8)	6.4 (4.4)
Simpson's <sup>d</sup>	3.9 (3.3)	4.6 (2.0)	4.3 (2.4)	4.6 (3.5)
Shannon-Wiener <sup>e</sup>	0.5 (0.2)	0.7 (0.2)	0.6 (0.2)	0.5 (0.3)
<b>Waterbirds</b>				
Species Richness	5.9 (3.5)	6.5 (4.0)	1.0 (1.0)	5.1 (4.0)
Simpson's <sup>d</sup>	1.3 (1.8)	3.3 (2.0)	1.0 (1.3)	3.7 (3.0)
Shannon-Wiener <sup>e</sup>	0.4 (0.8)	0.5 (0.2)	0.1 (0.2)	0.4 (0.3)

<sup>a</sup> n=12; <sup>b</sup> n=11; <sup>c</sup> n=10;

<sup>d</sup> Simpson's Index of Diversity,  $1/D; D = \sum \frac{n_i(n_i - 1)}{N(N - 1)}$  ;

<sup>e</sup> Shannon-Wiener Diversity Index,  $H' = -\sum p_i \ln p_i$

**Table 14.** Mean (standard error) avian species richness in Flooded Wetlands during May-August, 2000-2001.

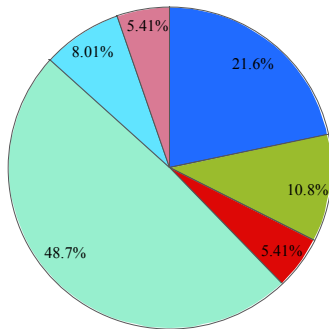
Variable	<u>Reclaimed Water</u>		<u>Reclaimed + Muted Tidal</u>	<u>Muted Tidal</u>
	MU1 <sup>a</sup>	MU3-8 <sup>a</sup>	OF1 <sup>a</sup>	DFG-15 <sup>a</sup>
<b>All Birds</b>				
Species Richness	9.6 (2.3)	8.0 (2.8)	6.0 (0.8)	8.1 (2.7)
Simpson's <sup>b</sup>	3.8 (3.2)	3.8 (2.5)	3.1 (0.8)	5.5 (2.8)
Shannon-Wiener <sup>c</sup>	0.4 (0.1)	0.5 (0.2)	0.6 (0.1)	0.7 (0.2)
<b>Waterbirds</b>				
Species Richness	4.8 (2.3)	2.3 (1.7)	0.4 (0.5)	4.1 (1.6)
Simpson's <sup>b</sup>	1.1 (1.6)	1.9 (1.3)	0.1 (0.5)	2.8 (1.8)
Shannon-Wiener <sup>c</sup>	0.2 (0.2)	0.3 (0.2)	0.0 (0.0)	0.4 (0.2)

<sup>a</sup> n=4;

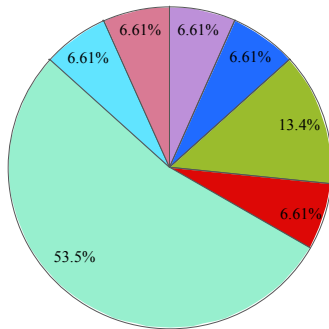
<sup>b</sup> Simpson's Index of Diversity,  $1/D; D = \sum \frac{n_i(n_i - 1)}{N(N - 1)}$  ;

<sup>c</sup> Shannon-Wiener Diversity Index,  $H' = -\sum p_i \ln p_i$

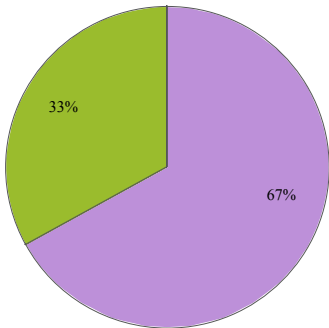
**September-October  
1999-2000**



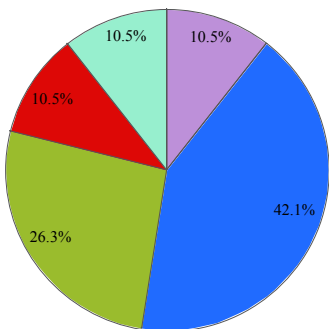
**Reclaimed Water, MU1**



**Reclaimed Water, MU3-8**

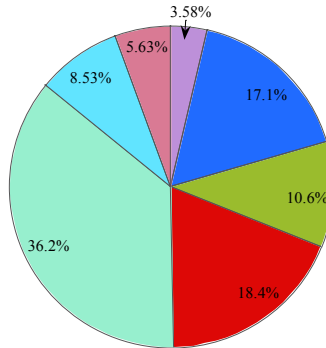


**Reclaimed + Muted Tidal, OF1**

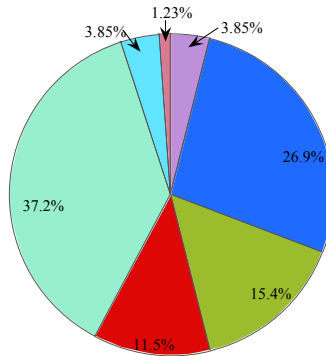


**Muted Tidal, DFG-15**

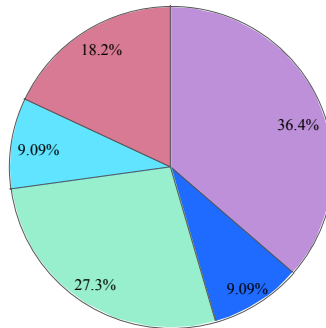
**November-April  
1999-2001**



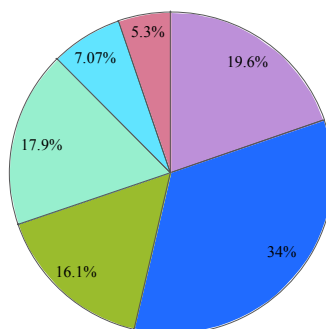
**Reclaimed Water, MU1**



**Reclaimed Water, MU3-8**

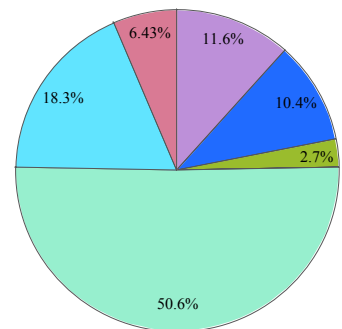


**Reclaimed + Muted Tidal, OF1**

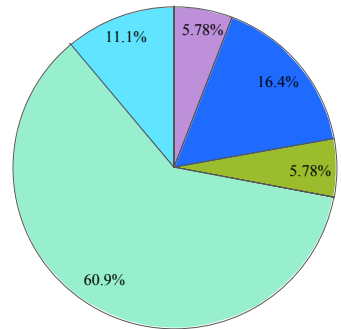


**Muted Tidal, DFG-15**

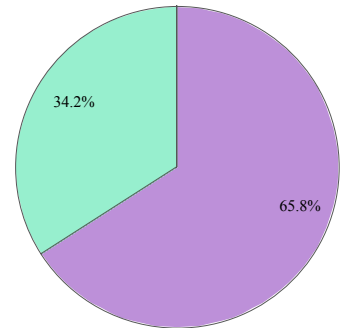
**May-August  
2000-2001**



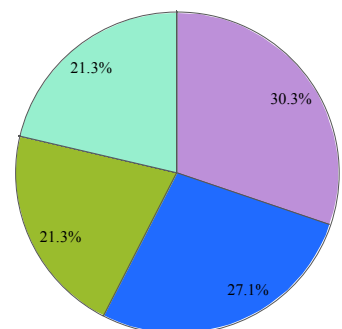
**Reclaimed Water, MU1**



**Reclaimed Water, MU3-8**



**Reclaimed + Muted Tidal, OF1**



**Muted Tidal, DFG-15**



**Figure 30.** Mean waterbird foraging guild species richness in flooded wetland habitats during Hudeman Slough Case Study monitoring, 1999-2001.

**Table 15.** Mean (standard error) avian densities (no. birds/study plot) in Open Water habitats during the Hudeman Slough Enhancement Wetlands Case Study.

Number of Birds	<u>Reclaimed Water</u>		<u>Seasonal Ponds</u>	
	OF2	MU3-9	MU3-10	DFG-13
<b>September-October, 1999-2000</b>				
<b>All Birds</b>	175.7 (162.6) <sup>a</sup>	22.5 (31.4) <sup>b</sup>	8.5 (9.9) <sup>b</sup>	23.0 (25.3) <sup>b</sup>
<b>Waterbirds</b>	4.0 (2.7) <sup>a</sup>	15.3 (29.2) <sup>b</sup>	0.0 <sup>b</sup>	0.0 <sup>b</sup>
<b>November-April, 1999-2001</b>				
<b>All Birds</b>	30.6 (18.9) <sup>c</sup>	72.7 (55.0) <sup>d</sup>	23.4 (16.4) <sup>d</sup>	19.8 (12.5) <sup>d</sup>
<b>Waterbirds</b>	6.8 (8.9) <sup>c</sup>	50.0 (52.5) <sup>d</sup>	2.7 (2.3) <sup>d</sup>	5.3 (7.7) <sup>d</sup>
<b>May-August, 2000-2001</b>				
<b>All Birds</b>	43.9 (49.8) <sup>b</sup>	93.1 (132.4) <sup>b</sup>	30.5 (24.2) <sup>b</sup>	26.1 (19.5) <sup>b</sup>
<b>Waterbirds</b>	4.0 (5.8) <sup>b</sup>	22.6 (16.4) <sup>b</sup>	0.0 <sup>b</sup>	0.9 (1.6) <sup>b</sup>

<sup>a</sup> n=3; <sup>b</sup> n=4; <sup>c</sup> n=11; <sup>d</sup> n=12

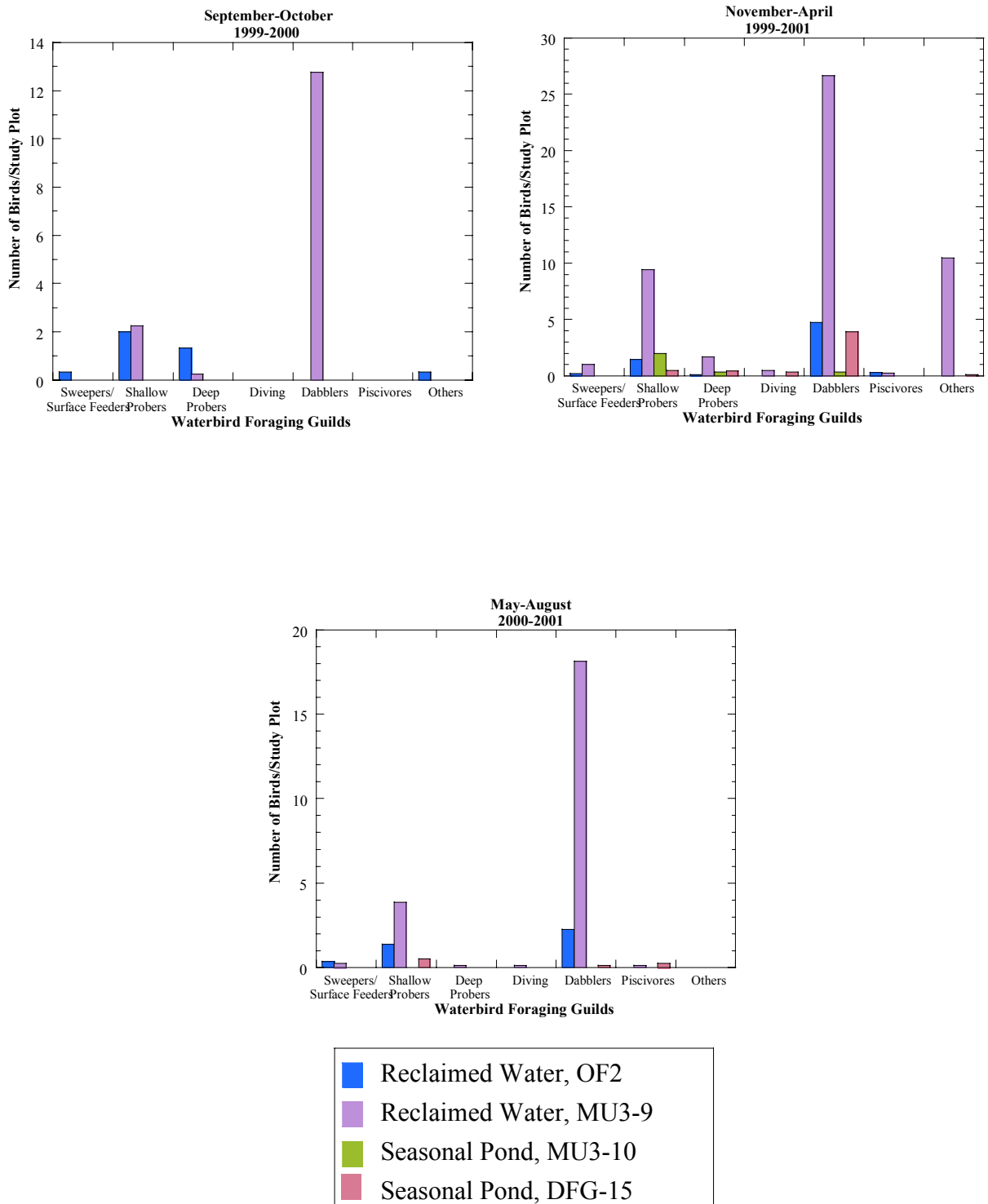
**Table 16.** Mean (standard error) avian densities (no. birds/study plot) in Flooded Wetlands during the Hudeman Slough Enhancement Wetlands Case Study.

Number of Birds	<u>Reclaimed Water</u>		<u>Reclaimed + Muted Tidal</u>	<u>Muted Tidal</u>
	MU1	MU3-8	OF-1	DFG-15
<b>September-October, 1999-2000</b>				
<b>All Birds</b>	181.5 (277.0) <sup>a</sup>	151.0 (123.9) <sup>b</sup>	47.3 (35.9) <sup>b</sup>	87.8 (92.1) <sup>a</sup>
<b>Waterbirds</b>	57.9 (120.4) <sup>a</sup>	122.3 (110.0) <sup>b</sup>	4.0 (6.9) <sup>b</sup>	70.0 (100.3) <sup>a</sup>
<b>November-April, 1999-2001</b>				
<b>All Birds</b>	75.4 (83.7) <sup>c</sup>	180.3 (237.6) <sup>c</sup>	43.7 (27.3) <sup>d</sup>	27.6 (40.4) <sup>e</sup>
<b>Waterbirds</b>	43.0 (32.9) <sup>c</sup>	97.1 (77.6) <sup>c</sup>	5.4 (11.7) <sup>d</sup>	24.4 (39.4) <sup>e</sup>
<b>May-August, 2000-2001</b>				
<b>All Birds</b>	52.9 (27.1) <sup>a</sup>	80.1 (71.1) <sup>a</sup>	34.5 (10.7) <sup>a</sup>	38.0 (19.7) <sup>a</sup>
<b>Waterbirds</b>	22.6 (18.8) <sup>a</sup>	6.5 (5.2) <sup>a</sup>	0.5 (0.8) <sup>a</sup>	21.5 (22.1) <sup>a</sup>

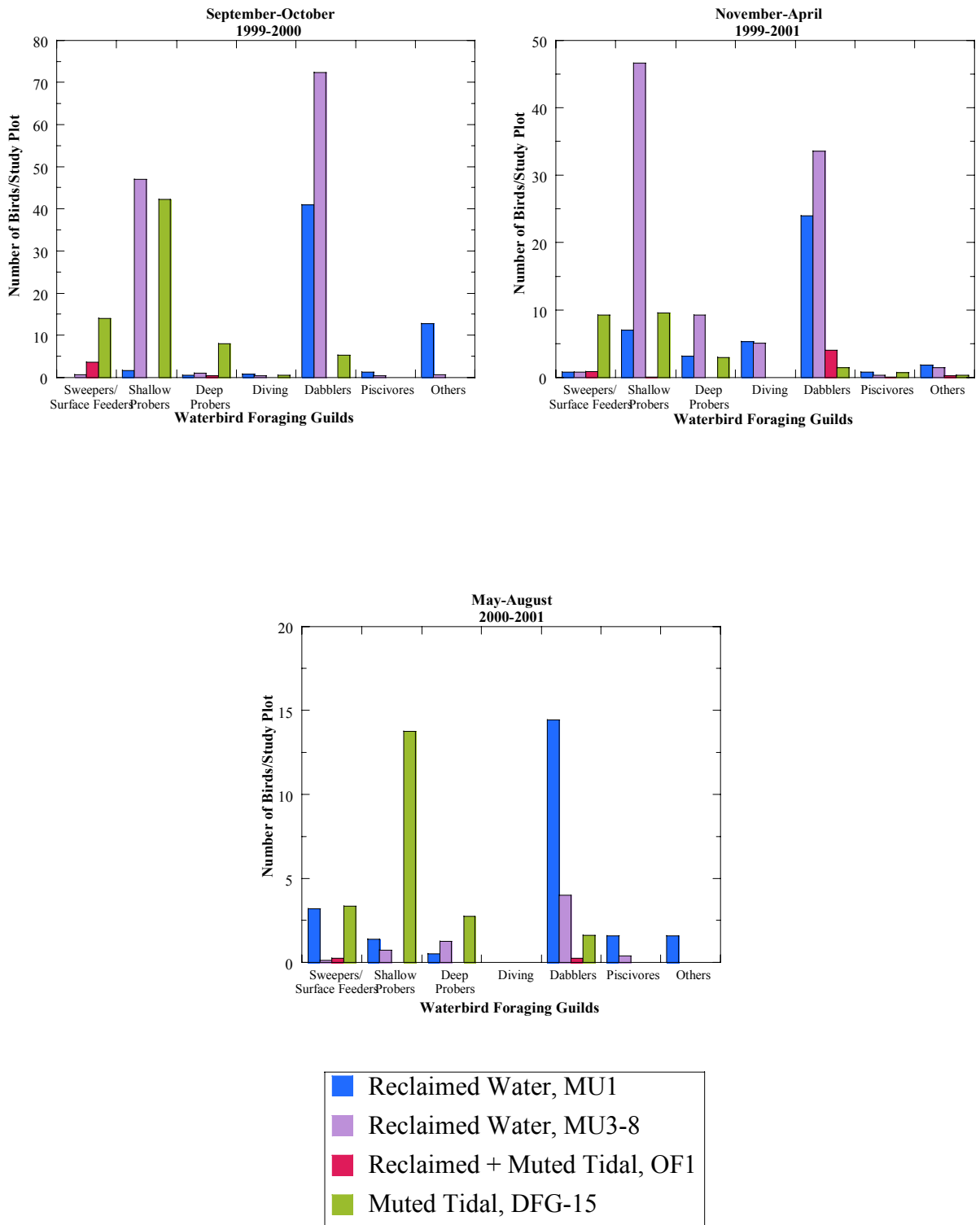
<sup>a</sup> n=4; <sup>b</sup> n=3; <sup>c</sup> n=12; <sup>d</sup> n=11; <sup>e</sup> n=10

A similar pattern was observed during the November-April study period (Table 16). However, waterbird densities in MU3-8 were reversed, with shallow probers being the dominant birds observed ( $\bar{x}$ =46.6 birds/plot), followed by dabblers ( $\bar{x}$ =33.6 birds/plot, Figure 32). In the Muted Tidal plot, shallow probers and sweepers/surface feeders were co-dominant ( $\bar{x}$ =9.6 and 9.3 birds/plot, respectively). The Reclaimed Water + Muted Tidal plot had a slightly greater mean number of waterbirds during the November-April study period than the September-October period, but there was a definite shift from sweepers/surface feeders to dabblers ( $\bar{x}$ =4.0 birds/plot).

During the May-August study period, waterbird densities declined in Reclaimed Water study plot MU3-8, with a mean waterbird density of only 6.5 birds/plot (Table 16). The Reclaimed Water + Muted Tidal plot also continued to have very low mean waterbird densities compared to the remaining study plots (Figure 32). However, Reclaimed Water study plot MU1 and the Muted Tidal plot still had relatively high numbers of waterbirds (43 percent and 57 percent of birds observed, respectively). Dabblers were still the greatest density of waterbirds in the Reclaimed Water unit MU1 ( $\bar{x}$ =14.4 birds/plot), while shallow probers were the highest density in the Muted Tidal unit ( $\bar{x}$ =13.8 birds/plot).



**Figure 31.** Mean waterbird foraging guild densities (no.birds/study plot) in open water habitats during the Hudeman Slough Case Study monitoring, 1999-2001.



**Figure 32.** Mean waterbird foraging guild densities (no.birds/study plots) in flooded wetland habitats during the Hudeman Slough Case Study monitoring, 1999-2001.

### ***Species Richness, Diversity, and Density for Monitoring Study***

*Open Water.* Waterbird densities for the entire monitoring study were significantly greater in Reclaimed Water study plot MU3-9 than in other Open Water study plots (Table 17). Significant differences in waterbird species richness and diversity ( $H'$ ) were detected between Reclaimed Water plot MU3-9 and the other Open Water plots. No significant difference in species richness, species diversity ( $H'$ ), or density was detected between Reclaimed Water study plot OF2 and the Seasonal Ponds.

*Flooded Wetlands.* During the entire study period, median waterbird species richness, species diversity, and densities in the Reclaimed Water + Muted Tidal study plot were significantly different from other flooded wetlands (Table 18). The Reclaimed Water + Muted Tidal unit had fewer birds and less diversity than the other flooded wetland plots. No significant difference was detected between the Reclaimed Water and Muted Tidal study plots.

**Table 17.** Median waterbird species richness, species diversity, and densities (no. birds/study plot) in Open Water habitats during the Hudeman Slough Enhancement Wetlands Case Study, September 1999-August 2001.

Variable	Reclaimed Water		Seasonal Ponds		
	OF2	MU3-9	MU3-10	DFG-13	
<b>Species Richness</b>	1.0 <sup>a</sup>	3.5 <sup>b</sup>	0.0 <sup>a</sup>	0.0 <sup>a</sup>	$\alpha=0.05$
<b>Shannon-Wiener<sup>c</sup></b>	0.0 <sup>a</sup>	0.4 <sup>b</sup>	0.0 <sup>a</sup>	0.0 <sup>a</sup>	$\alpha=0.05$
<b>Density</b>	2.5 <sup>a</sup>	19.5 <sup>b</sup>	0.0 <sup>a</sup>	0.0 <sup>a</sup>	$\alpha=0.05$

<sup>a</sup> Medians followed by the same letter were not significantly different (Kruskal-Wallis, Bonferroni z-value<2.6383).

<sup>b</sup> Median significantly different (Kruskal-Wallis, Bonferroni z-value>2.6383).

<sup>c</sup> Shannon-Wiener Diversity Index,  $H' = -\sum p_i \ln p_i$

**Table 18.** Median waterbird species richness, species diversity, and densities (no. birds/study plot) in Flooded Wetlands during the Hudeman Slough Enhancement Wetlands Case Study, September 1999-August 2001.

Variable	Reclaimed Water		Reclaimed+Muted Tidal	Muted Tidal	
	MU1	MU3-8	OF1	DFG-15	
<b>Species Richness</b>	5.5 <sup>a</sup>	3.0 <sup>a</sup>	0.5 <sup>b</sup>	5.0 <sup>a</sup>	$\alpha=0.05$
<b>Shannon-Wiener</b>	0.5 <sup>a</sup>	0.3 <sup>a</sup>	0.0 <sup>b</sup>	0.5 <sup>a</sup>	$\alpha=0.05$
<b>Density</b>	34.8 <sup>a</sup>	20.0 <sup>a</sup>	0.5 <sup>b</sup>	12.0 <sup>a</sup>	$\alpha=0.05$

<sup>a</sup> Medians followed by the same letter were not significantly different (Kruskal-Wallis, Bonferroni z-value<2.6383).

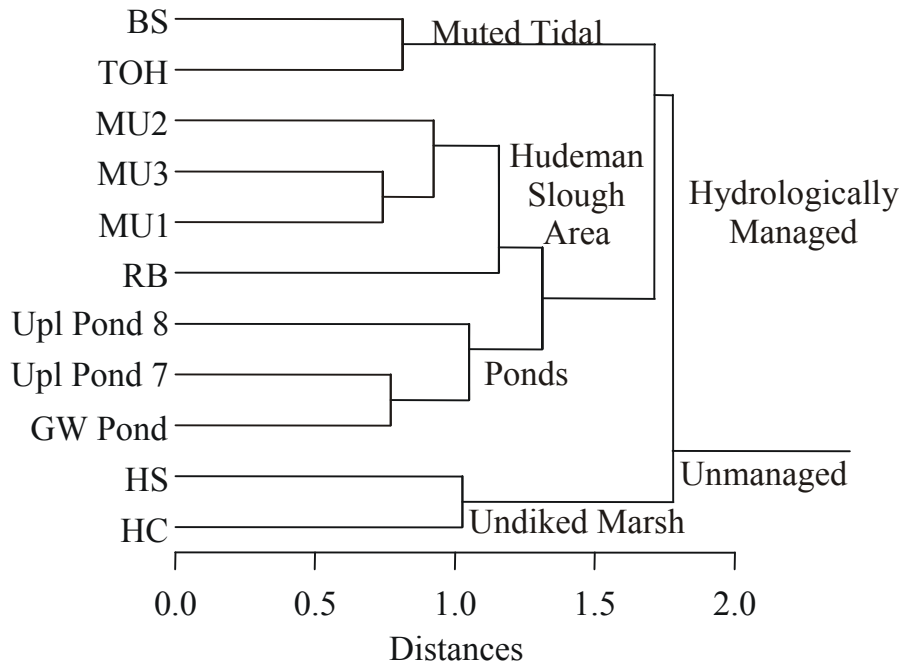
<sup>b</sup> Median significantly different (Kruskal-Wallis, Bonferroni z-value>2.6383).

### **Cluster Analysis**

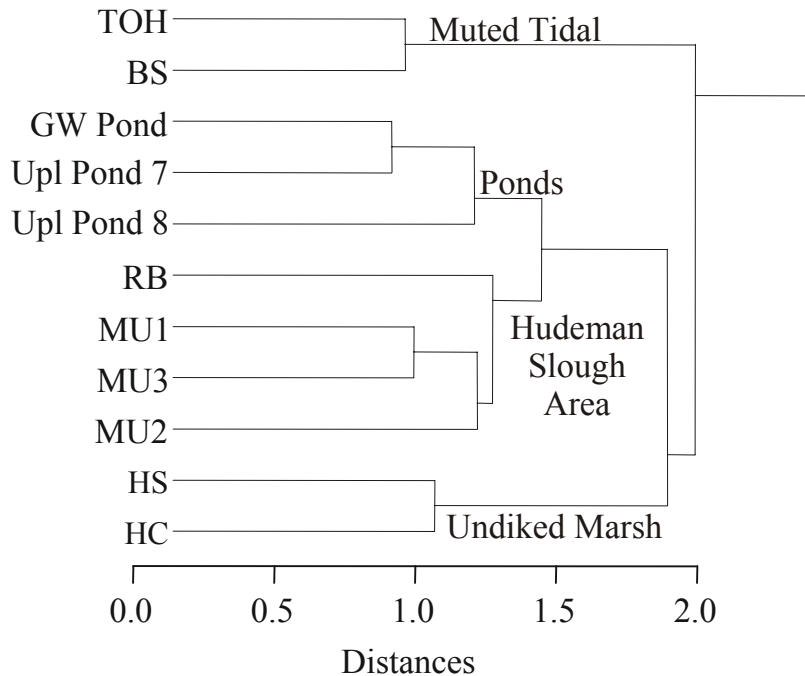
Cluster analysis, based on 36 variables, revealed four main clusters of sites, with several sub-clusters (Figure 33). In general, hydrologically managed sites separated from areas that were not hydrologically managed (Undiked Marsh). Within hydrologically managed sites, Muted Tidal sites (BS, TOH) that are principally tidal in nature were distinct from sites that are significantly influenced by “freshwater,” whether that be reclaimed water, pumped groundwater, or significant ponding and detention of upland run-off and precipitation. Hydrologically managed diked marshes were also split from hydrologically managed “upland” ponds. The sub-cluster of Reclaimed Water monitoring sub-units (MU1 and MU3) was grouped with another Hudeman Slough site (MU2) that is located in-between MU1 and MU3, but is not managed with reclaimed water. Rather, MU2 is inundated extensively with upland run-off and precipitation during the

## Cluster Analysis Dendrogram

Biotic and Abiotic Variable Model Without Contaminants



Biotic and Abiotic Variable Model with Contaminants



**Figure 33.** Dendrogram depicting results of classification analysis using biotic and abiotic variables.

winter and allowed to passively drain through a one-way tidegate (Passive Hydrologic Management monitoring unit). These Hudeman Slough sites, then, combined with an adjacent property that is managed using both reclaimed water and tidal flushing (RB/Ringstrom Bay; Reclaimed Water + Muted Tidal). For the “ponds,” a sub-cluster of perennially inundated or saturated ponds managed by either reclaimed water (Upland Pond 7) or pumped groundwater (GW Pond) were grouped with a pond that is only seasonally inundated or saturated with reclaimed water (Upland Pond 8).

Re-running the cluster analysis with six (6) sediment contaminant and 36 biotic and abiotic variables altered classification results slightly (Figure 33). The sub-clusters and four primary clusters remained the same, but the Undiked Marsh sampling locations actually grouped with most of the hydrologically managed monitoring units (Reclaimed Water, Reclaimed Water + Muted Tidal, Passive Hydrologic Management, and Groundwater Pond). Conversely, the Muted Tidal monitoring unit sampling locations were now clustered independently.